OLD DOMINION UNIVERSITY

In-medium nucleon Structure Functions through tagged Deep Inelastic Scattering with the LAD experiment

Carlos Ayerbe Gayoso
On behalf of the LAD experiment group

Jefferson Lab
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THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

TEL AVIV UNIVERSITY
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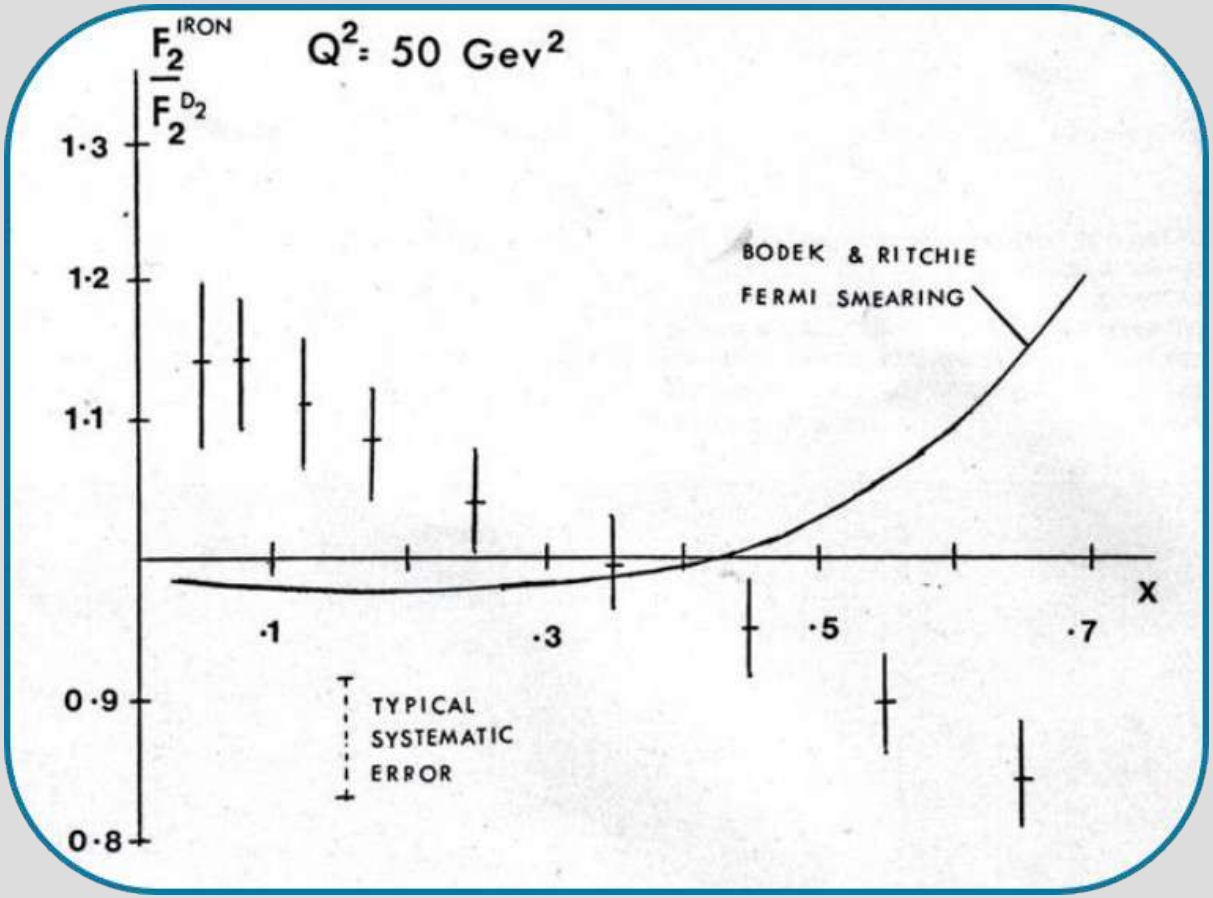
MIT

THE UNIVERSITY OF TENNESSEE
KNOXVILLE

The EMC Effect

Aubert et al., PLB (1983)

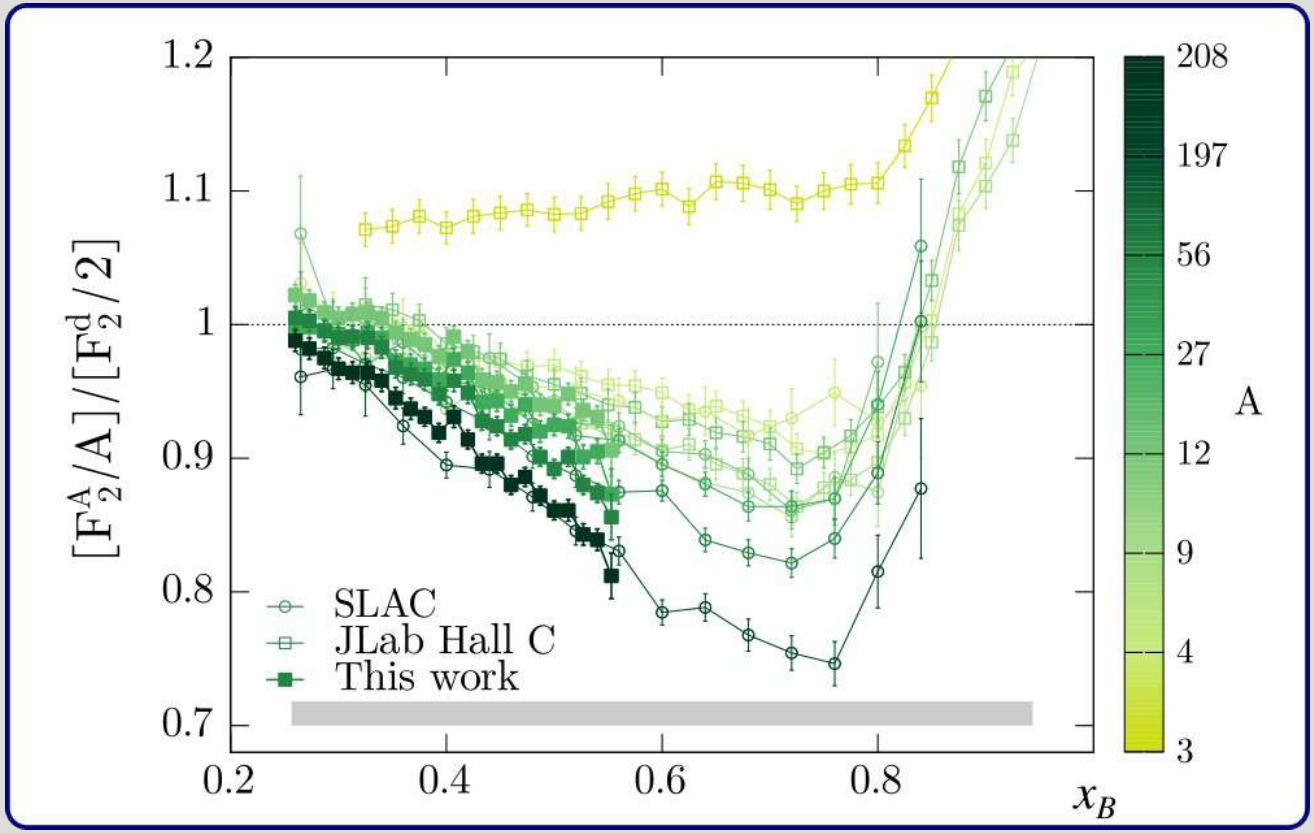


- Discovered 1983
  - >40 years
  - >1,000 papers
- SF bound nucleon ≠ SF free nucleon

The EMC Effect

- Present in all nuclei
- No consensus on a theoretical explanation

Schmookler et al., Nature (2019)



EMC explanations

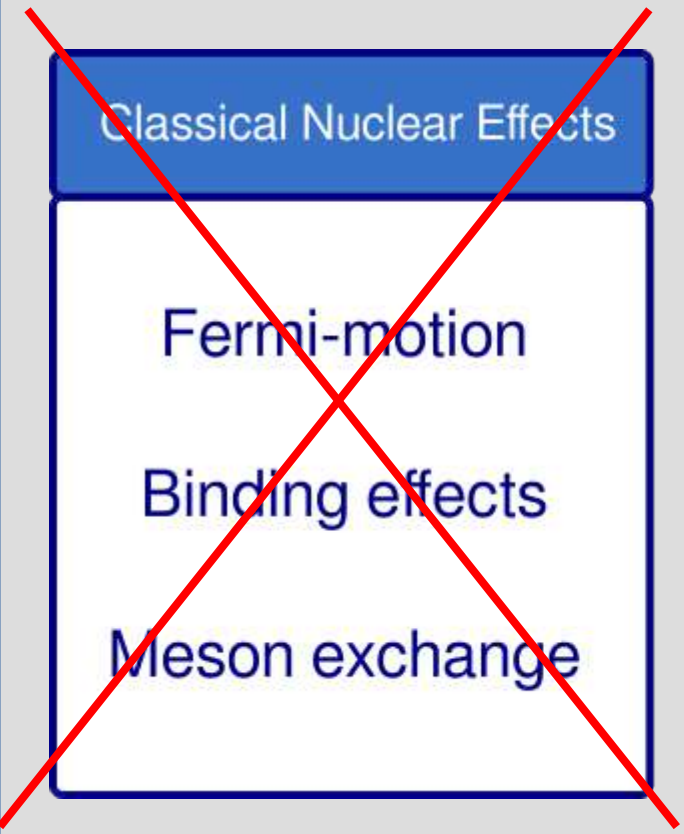
Classical Nuclear Effects

Fermi-motion

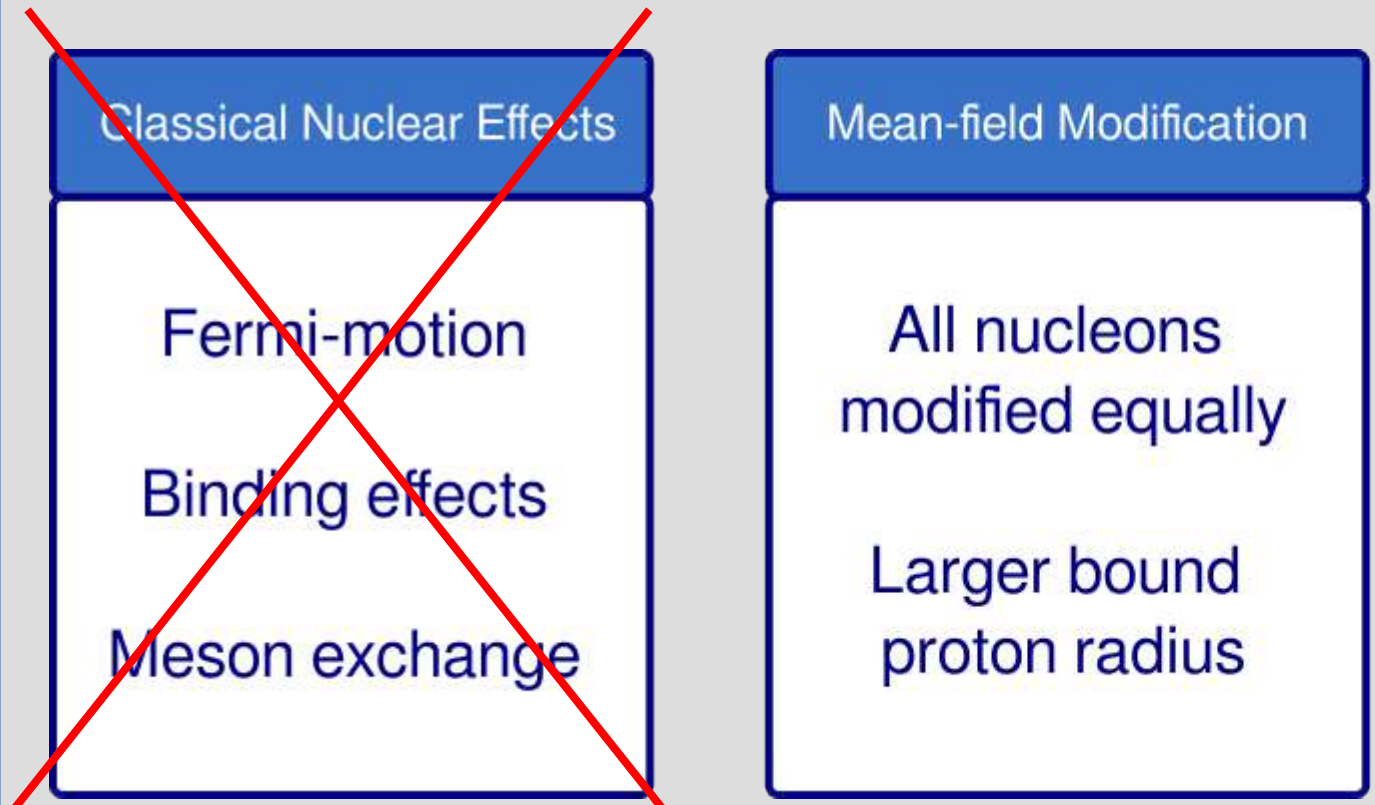
Binding effects

Meson exchange

EMC explanations



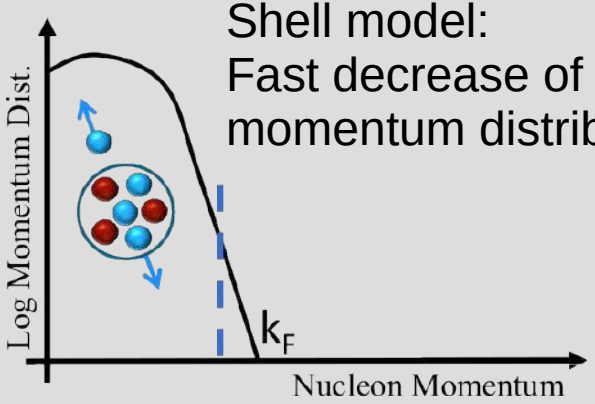
EMC explanations



EMC explanations

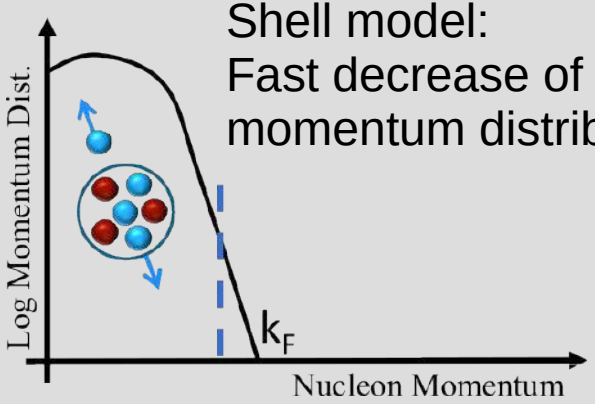
Classical Nuclear Effects	Mean-field Modification	SRC Modification
Fermi-motion Binding effects Meson exchange	All nucleons modified equally Larger bound proton radius	Virtuality-dependent modification → SRCs are highly virtual

Short Range Correlations



Shell model:
Fast decrease of the nucleon momentum distribution

Short Range Correlations



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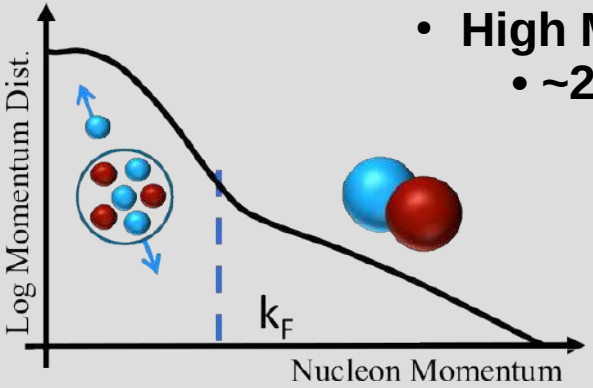
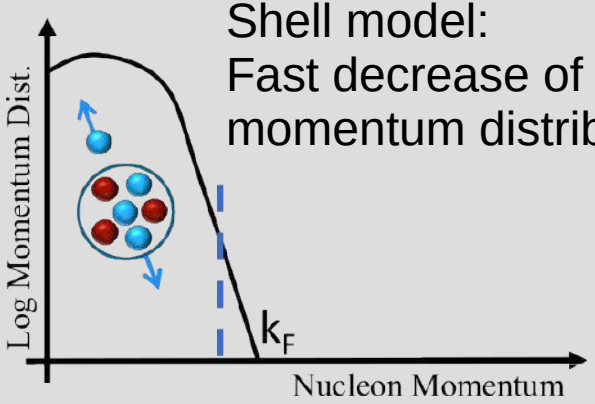


Short Range Correlations:

- **High Momentum States**
  - **~20% of nucleons**

Short Range Correlations



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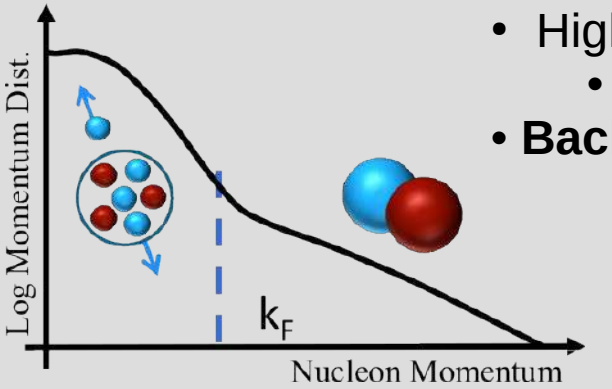
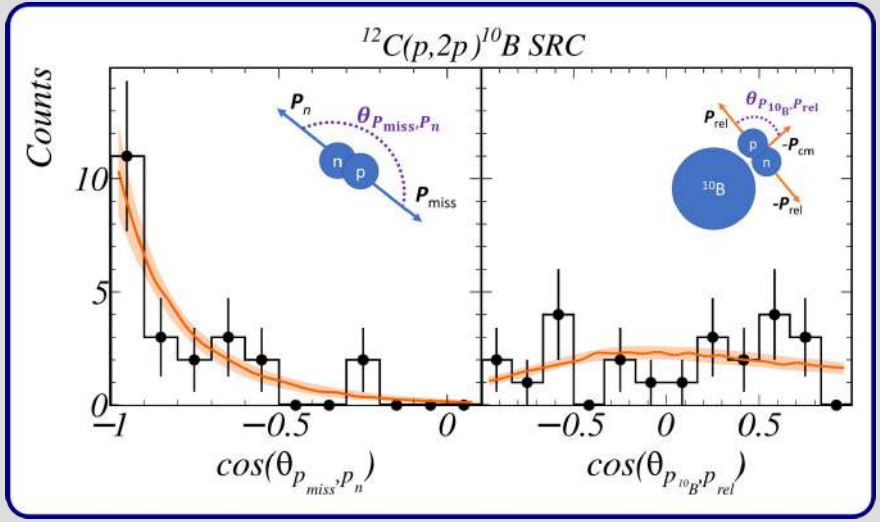


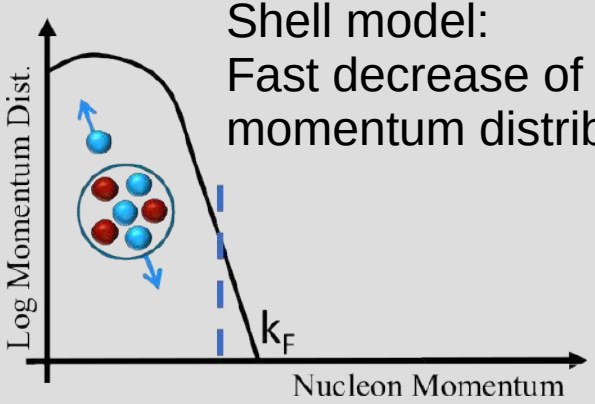
Short Range Correlations:

- High Momentum States
  - ~20% of nucleons
- **Back-to-back momentum**

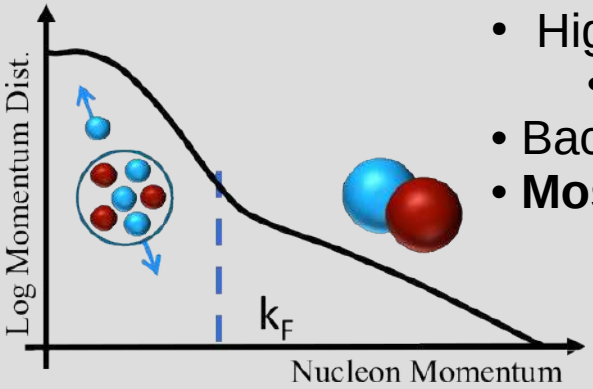
Patsyuk and Kahlbow et al., Nature Physics (2021)



Short Range Correlations



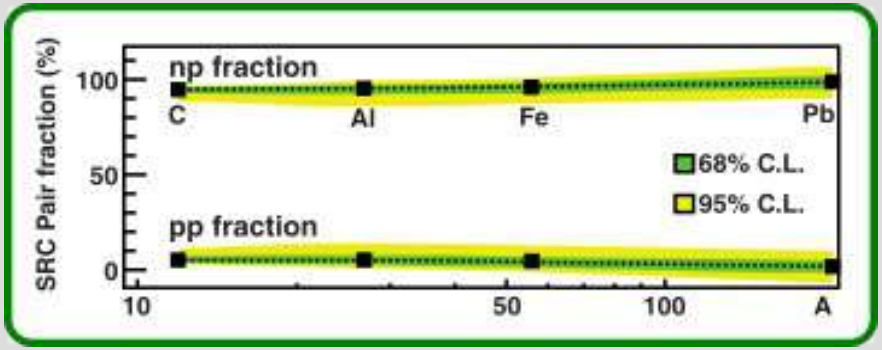
Shell model:
Fast decrease of the nucleon momentum distribution



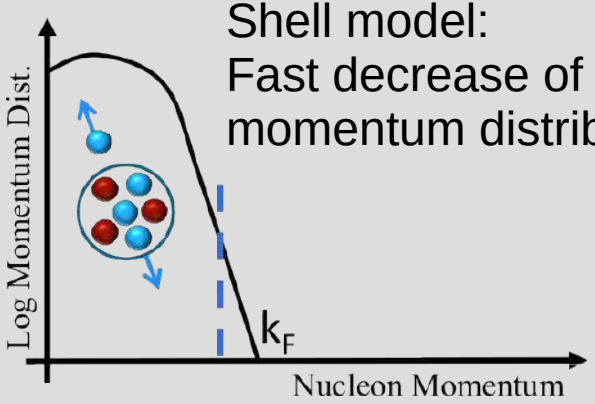
Short Range Correlations:

- High Momentum States
  - ~20% of nucleons
- Back-to-back momentum
- **Mostly np pairs**

Hen et al., Science (2014)



Short Range Correlations



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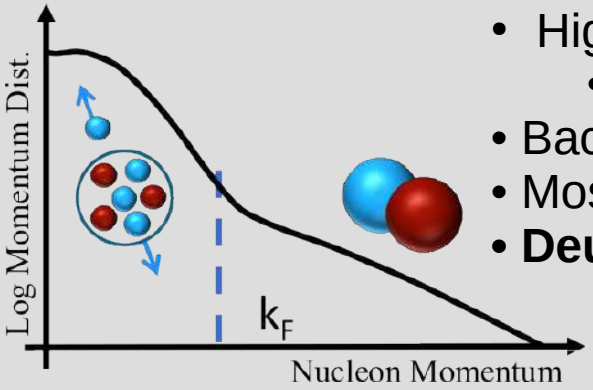
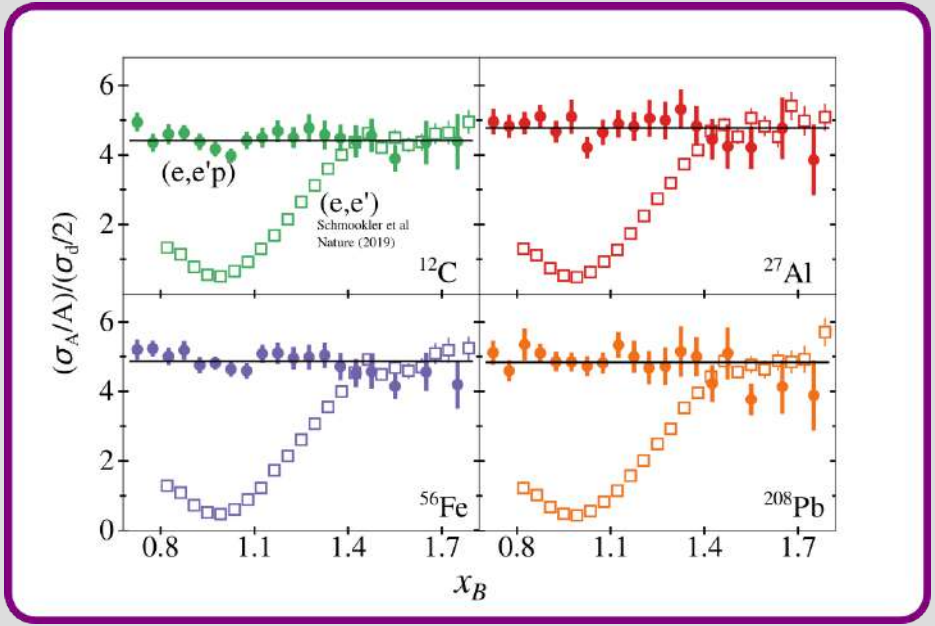


Short Range Correlations:

- High Momentum States
  - ~20% of nucleons
- Back-to-back momentum
- Mostly np pairs
- **Deuteron-like scaling**

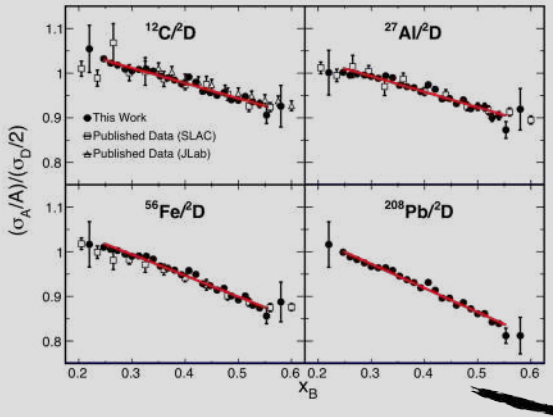


Korover and Denniston et al., PRC Lett. (2023)

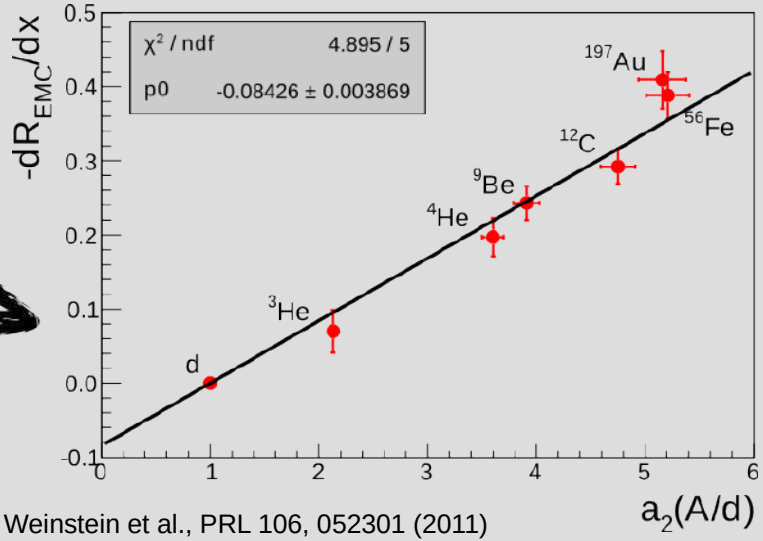
Slides courtesy of L. Ehinger

SRC Modification is well supported

There is a **high correlation** between the EMC effect strength and the probability of a nucleon to be part of SRC pairs for a given nuclei.

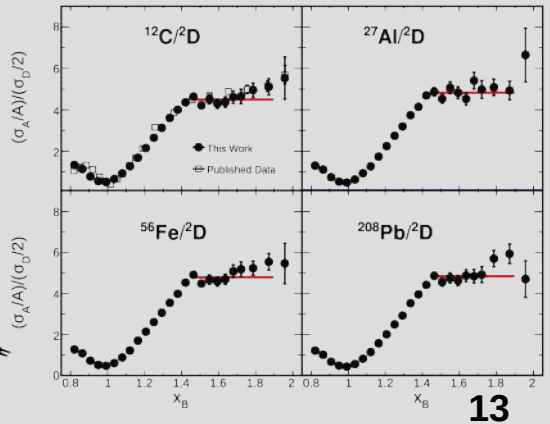


B. Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)



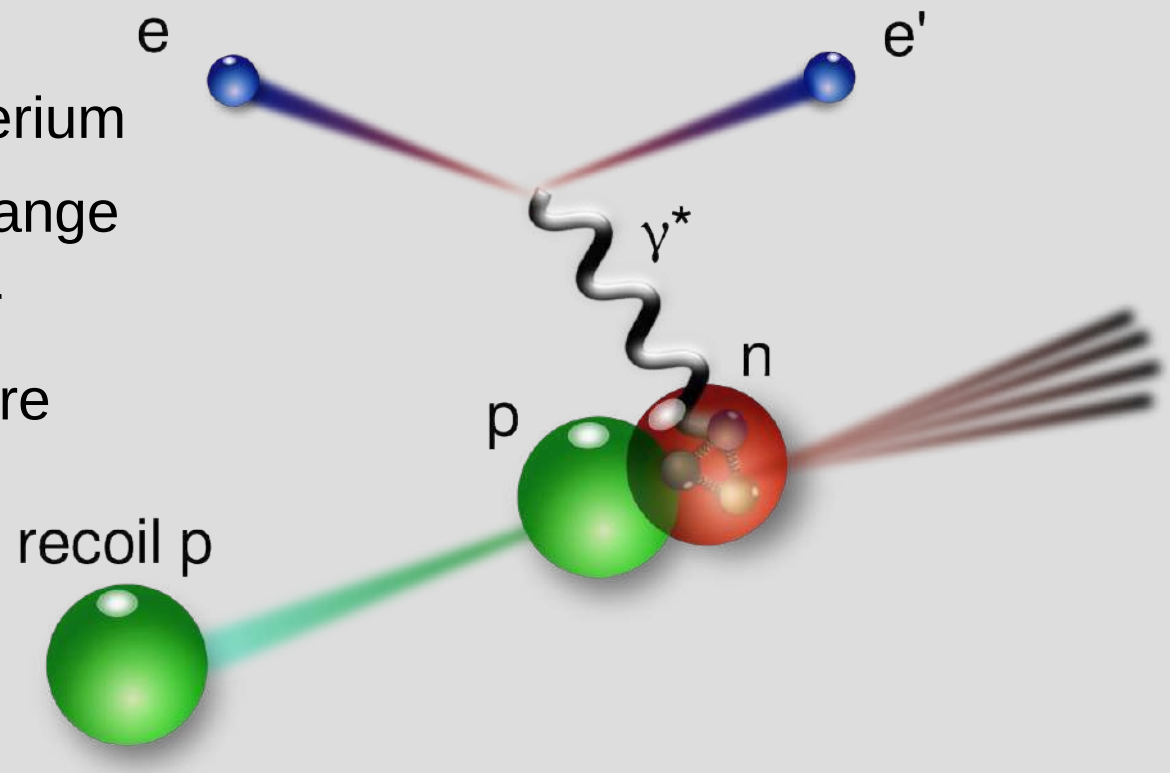
L. B. Weinstein et al., PRL 106, 052301 (2011)
O. Hen et al., PRC 85, 047301 (2012)

B. Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)



LAD will test the EMC-SRC hypothesis

- **Spectator-tagged DIS** on deuterium
- tag protons in 200–700 MeV/c range
- new Large Acceptance Detector
- Learn about the partonic structure of nucleons in SRCs



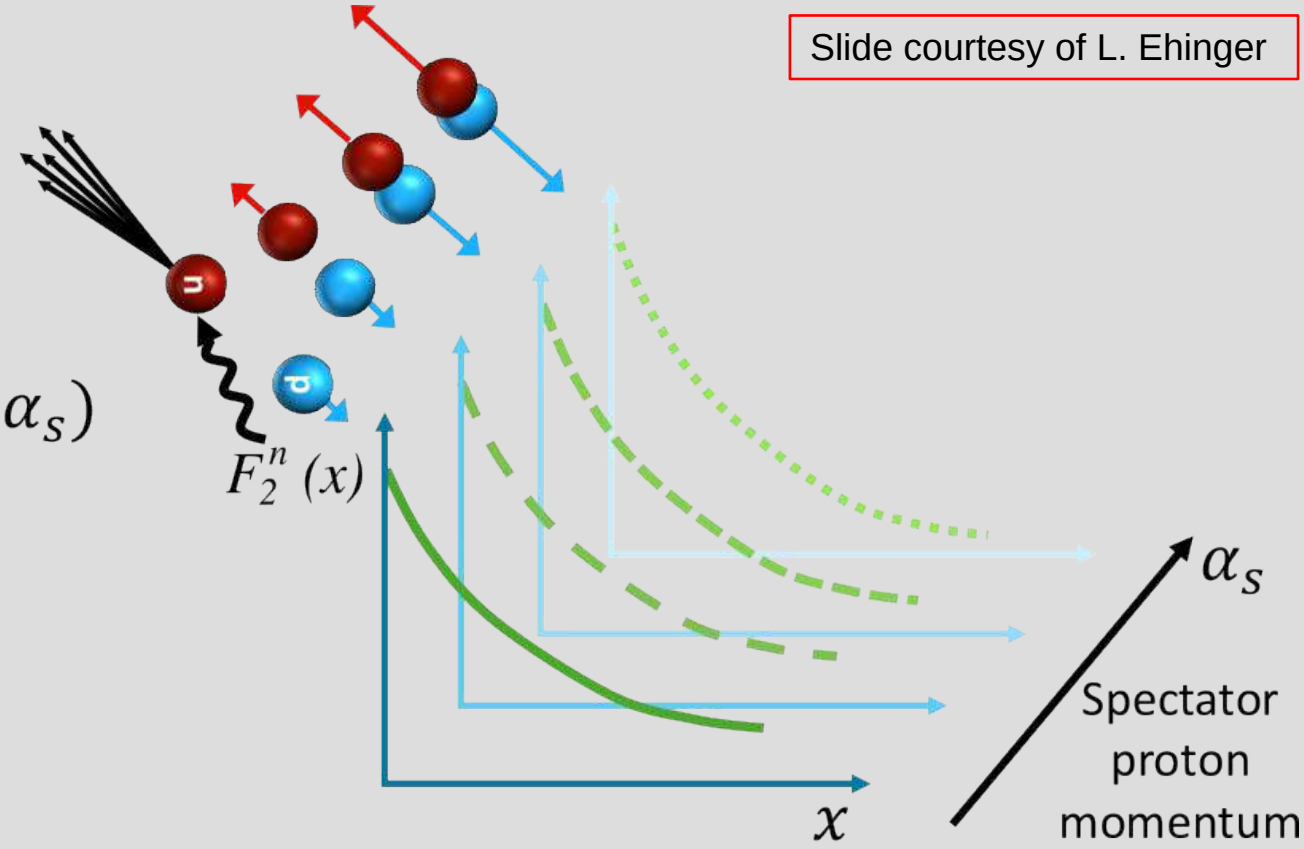
Spectator Tagged DIS

Slide courtesy of L. Ehinger

$$F_2(x, Q^2) \rightarrow F_2(x', Q^2, \alpha_s)$$

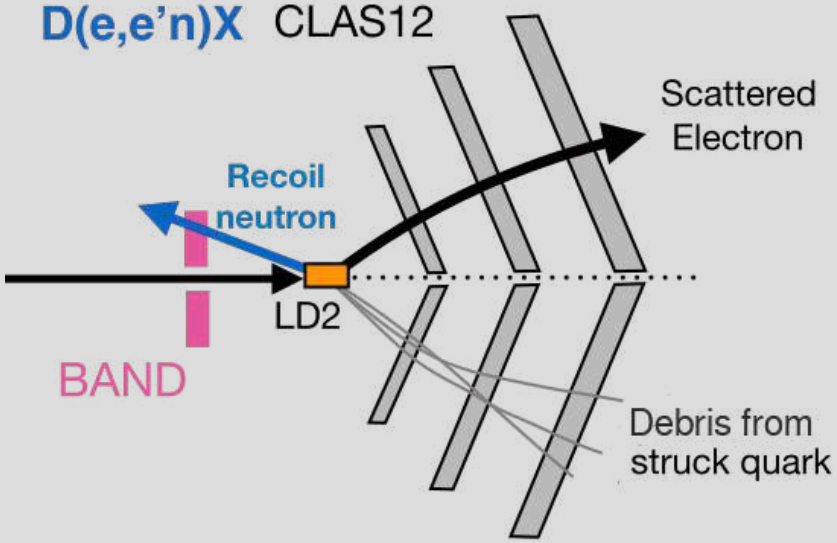
$$\alpha_s = \frac{E_s - p_s^z}{m_p}$$

Spectator final state can be described by the light-cone fraction



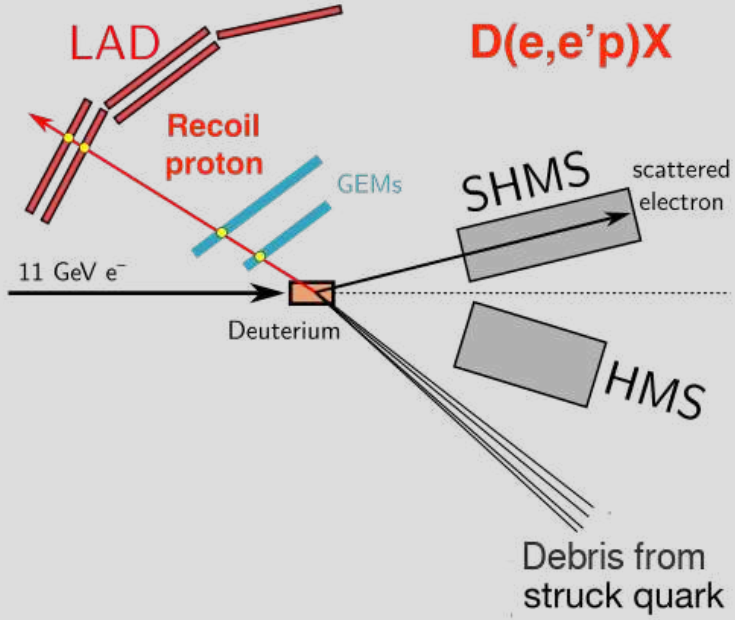
EMC-SRC tagged experiments at JLab

Hall B:
CLAS 12 + Backward Angle Neutron Detector (BAND)



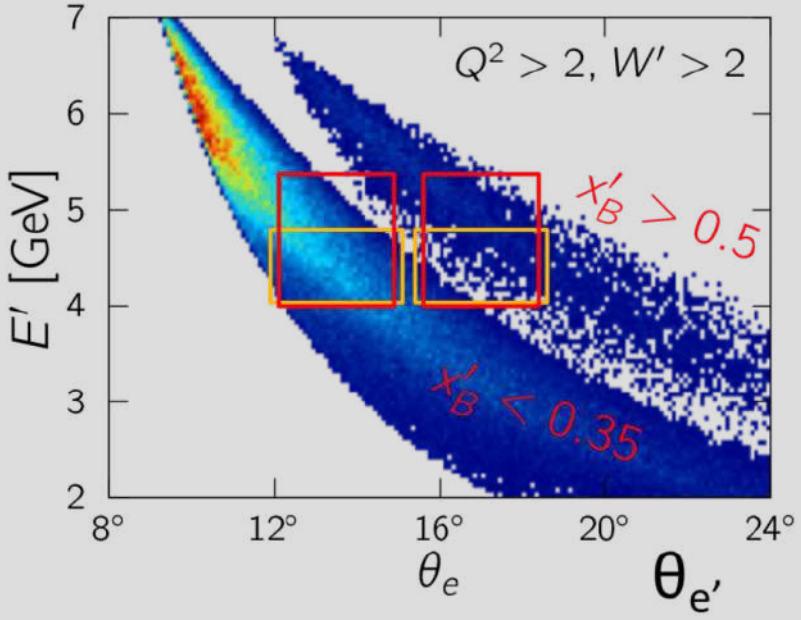
- Run Group B
- Analysis under review

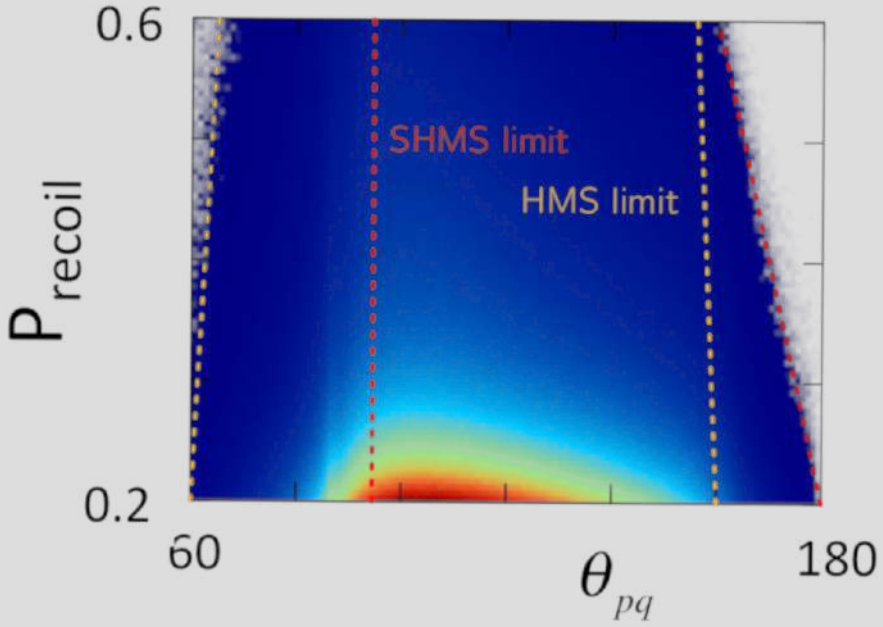
Hall C:
SHMS/HMS + Large Angle Detector (LAD)



Slide courtesy of A. Schmidt

LAD kinematic coverage

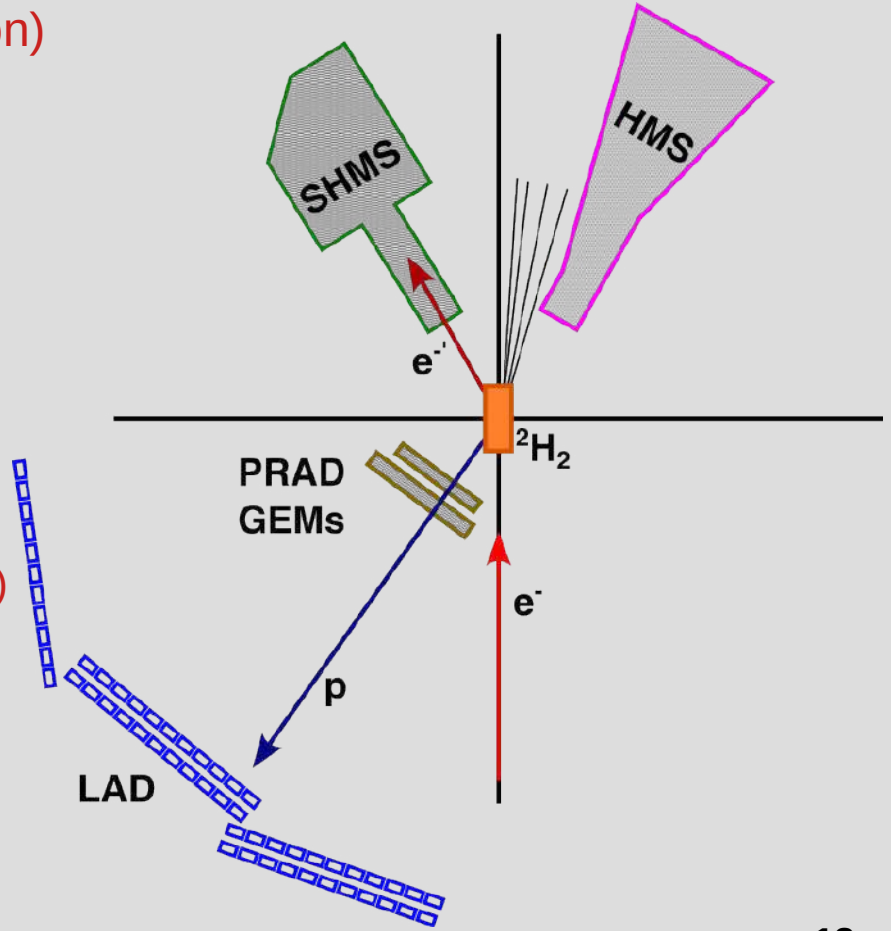




Courtesy of A. Schmidt

LAD Experimental Settings

- Beam energy **11 GeV** and 6.6 GeV (calibration)
  - Beam currents ~ 1-2uA
- Target: 20 cm liquid D2
- Luminosity: 1.2×10^{37} cm^{-2} s^{-1} per nucleon
- Standard HMS for electrons
  - Momentum: 4.4 GeV
  - Angles: **13.5°, 17°** and 21.7° (calibration)
- Standard SHMS for electrons
  - Momentum: **4.4 GeV** and 5.1 GeV (calibration)
  - Angles: 13.5° and 17°
- LAD detector for **recoil protons**
- PRAD GEMs for **tracking**
- Duration: 34 PAC days



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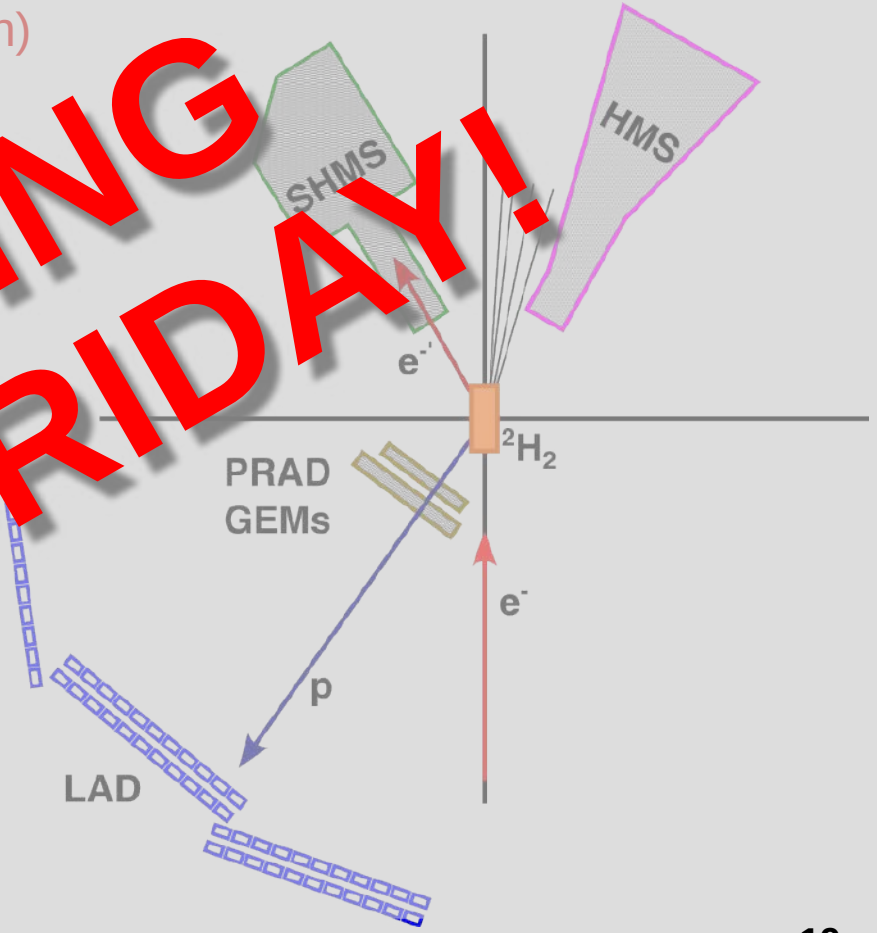
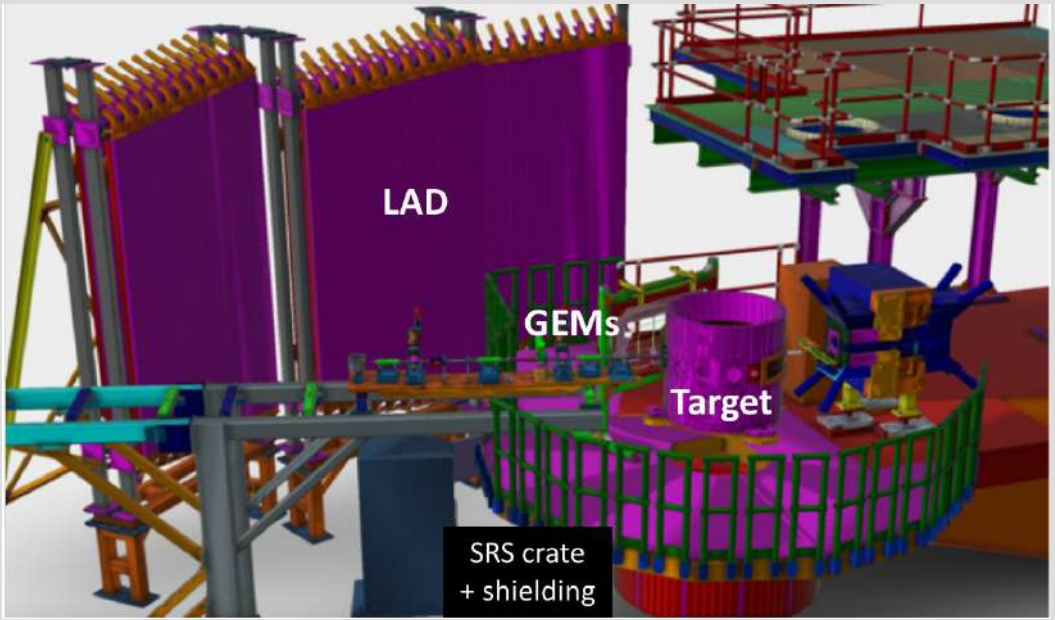
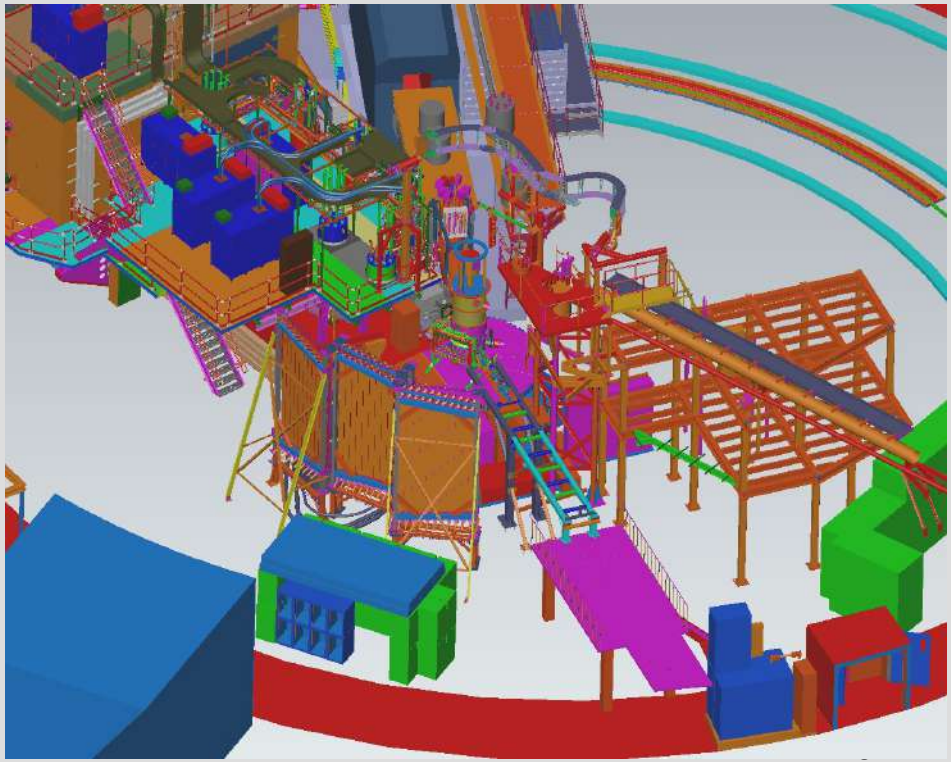
- Standard SHMS f electrons
  - Momentum: **4.4 G** and 5.1 GeV (calibration)
  - Angles: 13.5° and 17°
- LAD detector for **rec** protons
- PRAD GEMs for tracking
- Duration: 34 PAC days

STARTING NEXT FRIDAY!



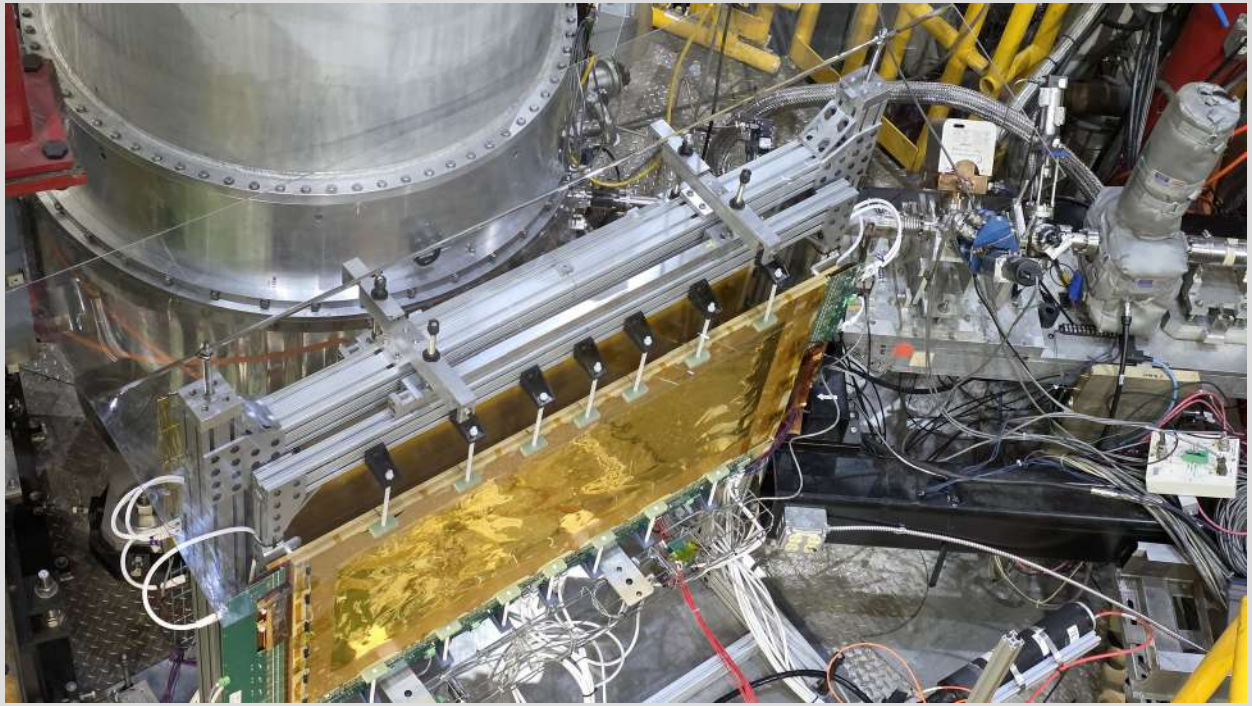
CAD drawings – Hall C+LAD





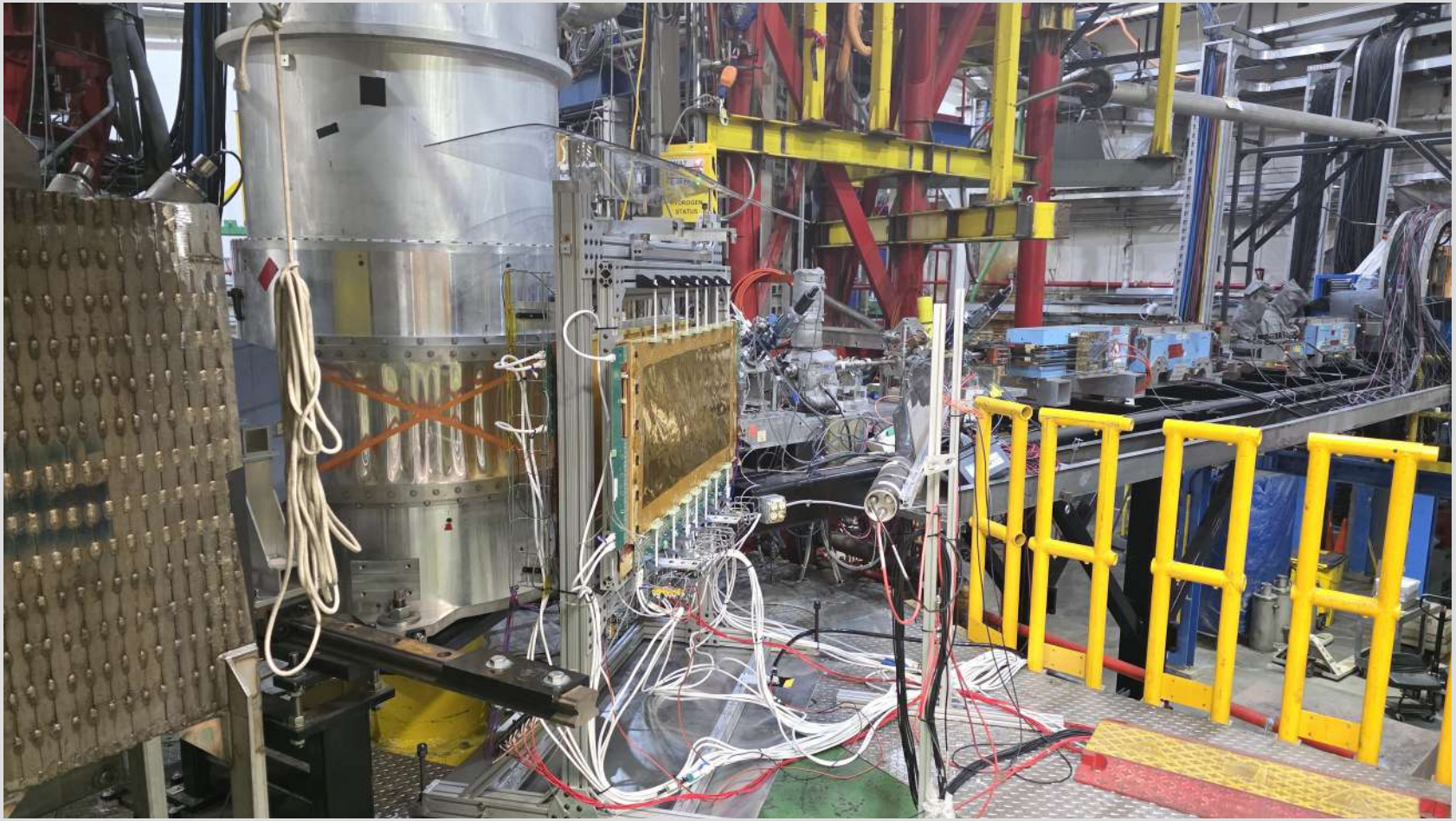
PRAD GEMs

2 GEMs next to scattering chamber
- <1m away from target
- Active area: 120 x 55 cm^2
- Separated by 20cm



Holly Szumila-Vance

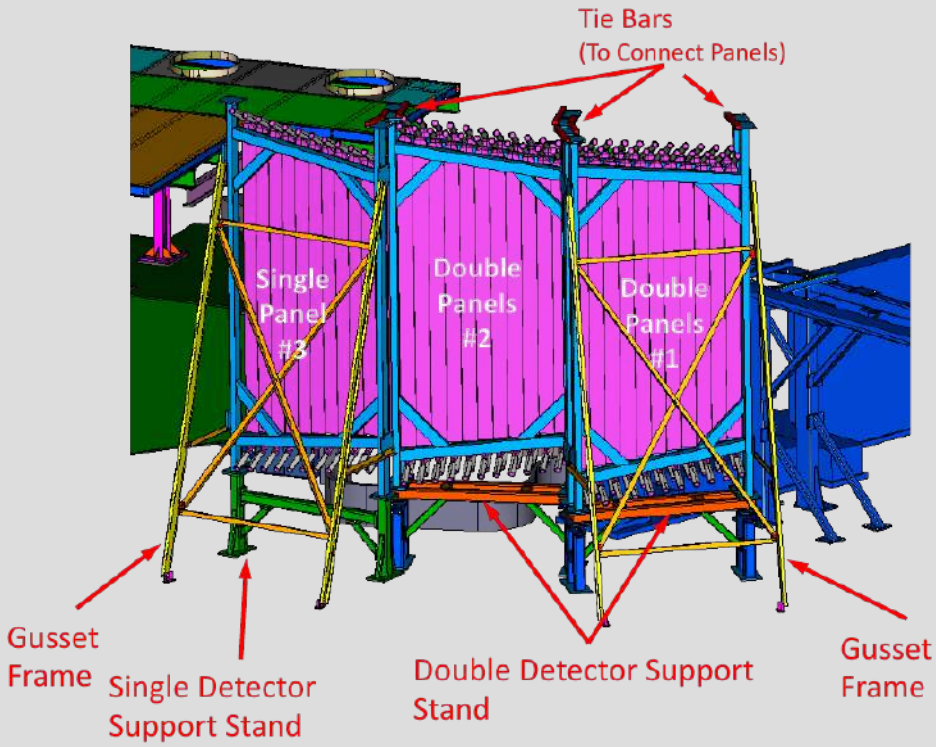
PRAD GEMs

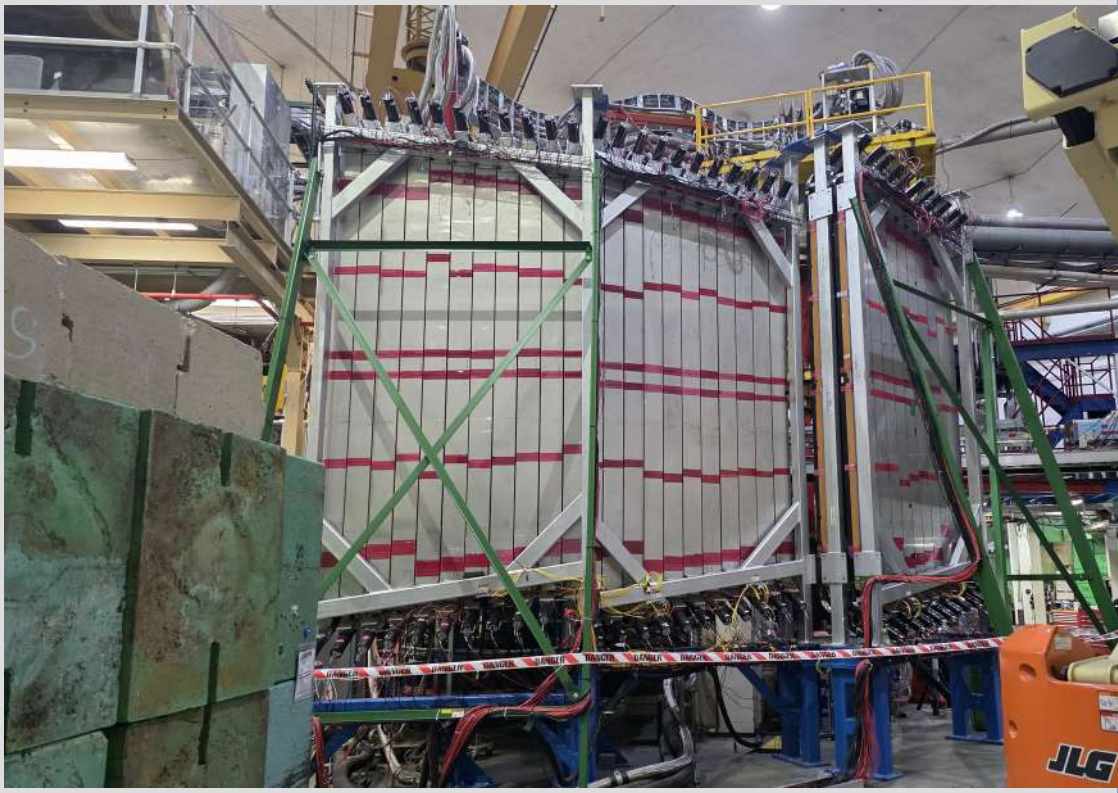


LAD (Hodoscope)

- CLAS 6 TOF scintillators refurbished at ODU

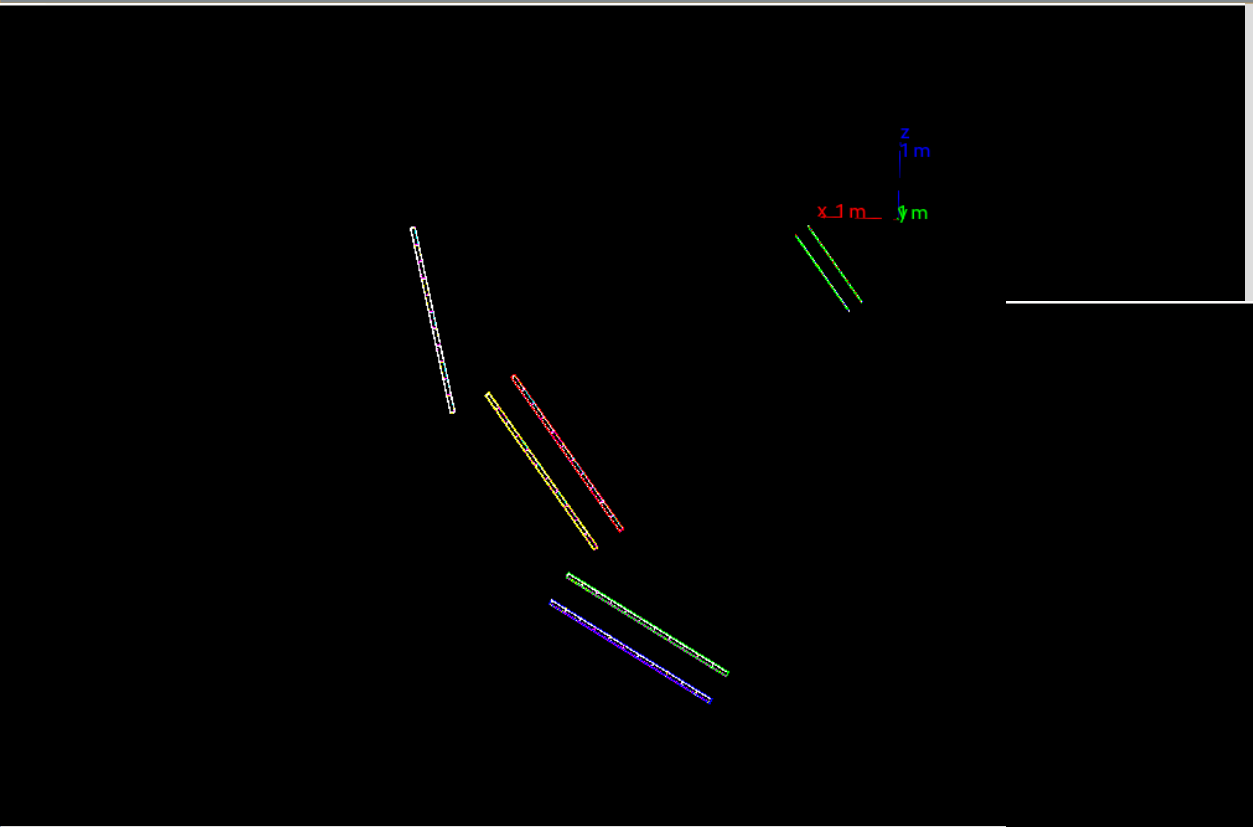
E.S.Smith – NIMA 432 (1999)



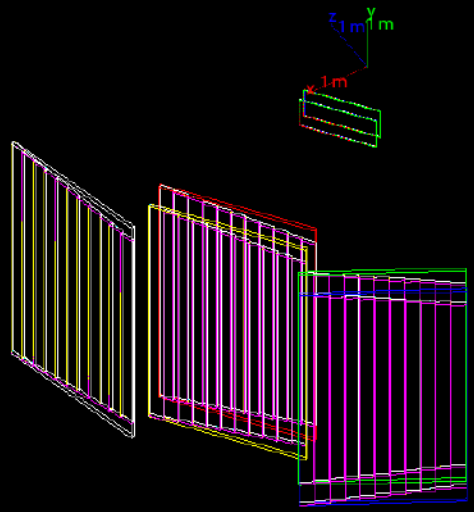


LAD Setup

Simulation



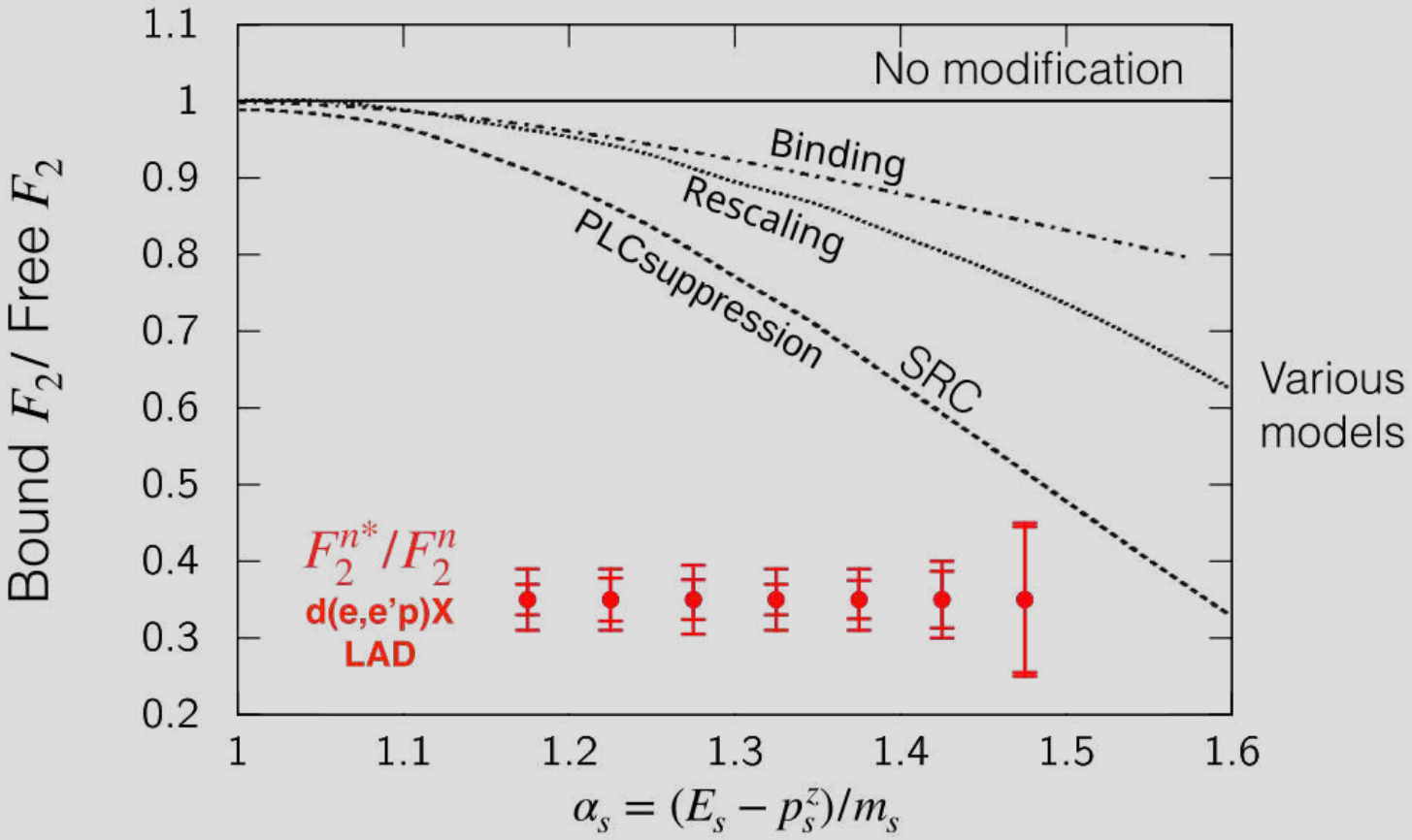
Carlos Ayerbe



Geant4 simulation of Hodoscope and GEMs

SimC will be used for electrons

d(e,e'p)X - Expected Results



Melnitchouk, Sargsian, Strikman, Z.Phys. A359, 99 (1997)












"With many contributions from the Hall C staff and assistance from MSU."

LAD in some links

- Large Area/Acceptance Detector (LAD) experiment (E12-11-107) Proposal. PAC 38, Aug 2011
  - Jeopardy June 21, 2021
- Experimental Readiness Review July 29, 2020
- A. Schmidt - LAD experiment in Hall C. Oct 19, 2021
- Hall C Meeting 2022 - O. Hen - The LAD Experiment: “In Medium Nucleon Structure Functions, SRC, and the EMC effect”
- Hall C Meeting 2022 - F. Hauenstein -The LAD Experiment: Status and Preparation
- Hall A/C Meeting 2023 - F. Hauenstein - Tagged DIS measurement with LAD
- Hall C Meeting 2025 - L. Ehinger - Measuring in-medium nucleon modification throug h spectator tagged DIS with the LAD experiment

MANDATORY BACKUP SLIDES

Run plan:

6 PAC days: Commission, calibration
34 PAC days: Physics runs

Condition	Scheduled work (Activities)	Total Time (PAC time)	Beam condition
Beam setup	- Sending beam to the Hall - Detector checking: scintillator, TOF, GEMs, spectrometers	2 shifts	6.6 GeV, 1uA
Low energy calibration	- Target LH2, elastic run for momentum calibration, and inclusive cross-section - SHMS at 17° and 5.048 GeV - HMS at 21.73° and 4.4 GeV - Delta-scan for momentum calibration (HMS: +/- 3%, 6%, 9%), (SHMS: -13%, -10%, -5%, 5%, 10%, 15%, 20%)	3 shifts	6.6 GeV, 10uA
			6

Slide courtesy of D. Nguyen

Condition	Scheduled work (Activities)	Total Time (PAC time)	Beam condition
3 pass -> 5 pass	- Beam checkout	1 shift	
Multi-foil target run	- HMS to 13.5° and 4.4 GeV - SHMS to 17° and 4.4 GeV - Doing GEM alignment - Install sieve and turn GEM off for optic calibration run	3 shifts 3 shifts	10.9 GeV 1 uA 10 uA
Luminosity scan	- Move to LD2 target and run with different currents to do luminosity scan for efficiency and luminosity check	1 shift	0.5, 0.7, 1.2, 1.5 uA
BCM calibration	- 2-3 times during run (needs other halls off)	1 shift	0.2 – 2uA
Physics run setting 1	- Target LD2 - HMS at 13.5° and 4.4 GeV - SHMS at 17° and 4.4 GeV - Dummy runs	13 days ~ 5% time	1 uA

Slide courtesy of D. Nguyen

7

Condition	Scheduled work (Activities)	Total Time (PAC time)	Beam condition
Physics run setting 2	- Target LD2 - HMS at 17° and 4.4 GeV - SHMS at 17° and 4.4 GeV - Dummy runs	8 days ~ 5% time	1uA
Physics run setting 3	- Target LD2 - HMS at 17° and 4.4 GeV - SHMS at 13,5° and 4.4 GeV - Dummy runs	13 days ~ 5% time	1uA

6 PAC days: Commission, calibration
34 PAC days: Physics runs

- ❑ Move of SHMS with people in hall due to GEMs and SHMS cables
- ❑ Surveys before and after run

Slide courtesy of D. Nguyen

8

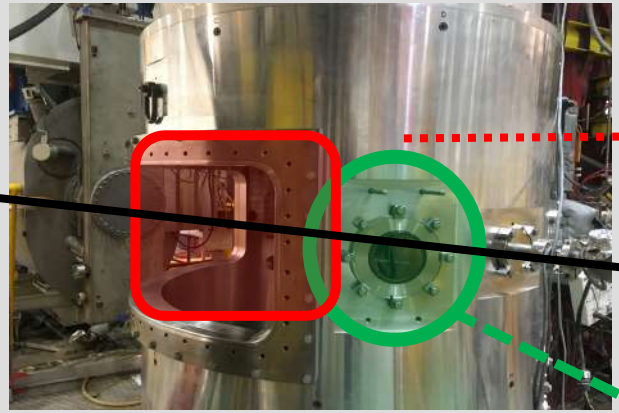
LAD objective

Measuring the in-medium neutron SF (related to EMC effect) at large momentum (SRC signature) tagging the recoil proton, offers an excellent test of the EMC-SRC hypothesis

The simplest nucleus to test is Deuterium

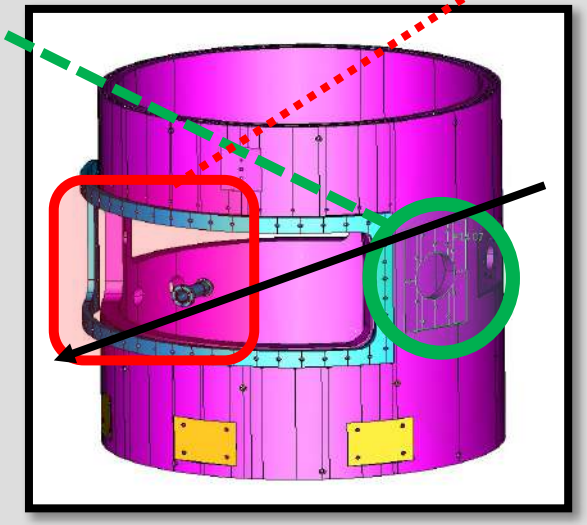
The Large Area Detector (LAD) Experiment was designed to investigate spectator Tagged-DIS (TDIS) involving **high-momentum nucleons** in deuterium. Its aim was to offer fresh perspectives on the overall origin of the EMC effect and, more specifically, **to assess the hypothesis** suggesting that the EMC Effect in nuclei primarily results from the modification of nucleons within short-range correlated (SRC) pairs.

Scattering Chamber with current pictures



16 inch

Beam direction
2022



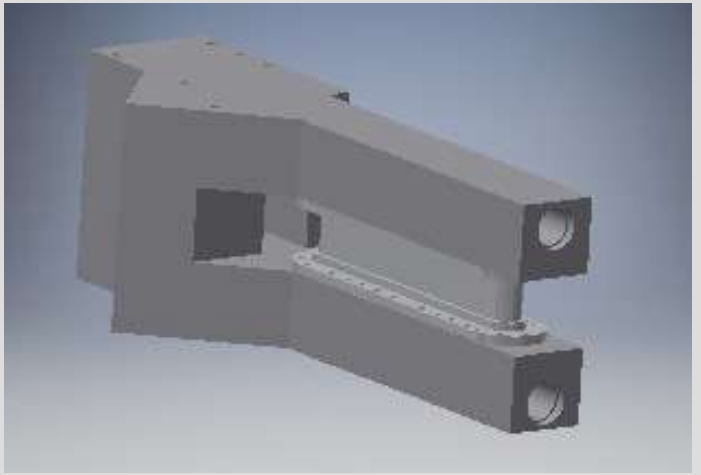
Beam direction 2022

LAD beam in flange

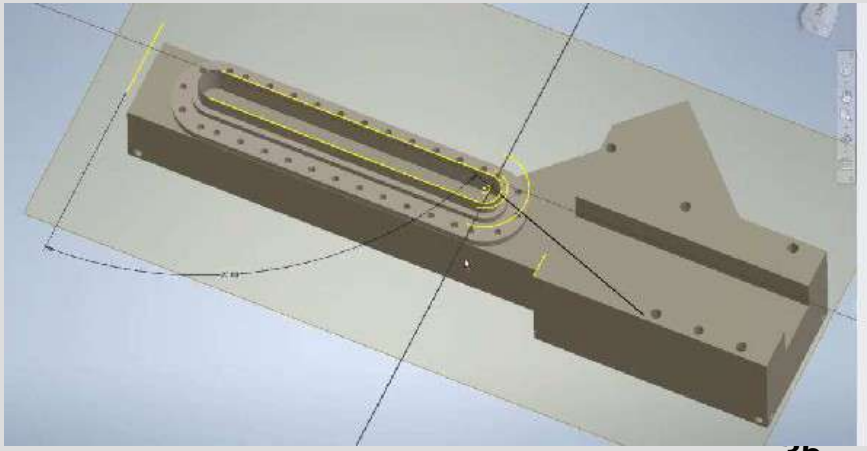
Slide courtesy of F. Hauenstein

Target Ladder

- **LH2**
- **LD2**
- **Empty/Dummy** target for wall subtraction
- **C-Multifoil** (5-6) for optics
- Usual **solid** target for beam checkout



Modified HAPPEX cell to accommodate LAD acceptance
- 20 cm length
- 2 cm width
- 2 cm height



Fabrication by JLab target group